

# **Contract Report for Land-based Southern Resident Killer Whale Vessel Interaction Study**

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## **Introduction**

In less than a killer whale (*Orcinus orca*) generation, people in the Pacific Northwest have gone from fearing these whales to adoring them (Ford *et al.* 2000). There are now approximately as many commercial whalewatching boats as there are southern resident killer whales for them to watch (Foote *et al.* 2004). These boats may have played a role in the recent decline of southern resident killer whales (Wiles 2004).

On the one hand, it stands to reason that repeated disturbance of wild animals could be implicated as a factor reducing the quality of life, foraging efficiency, fitness, or reproductive success of individual animals. Examples in the wildlife literature link anthropogenic disturbance to changes in foraging behavior (e.g., Galicia and Baldassarre 1997), reproductive success (e.g., Safina and Burger 1983), and mating system and social structure (e.g., Lacy and Martins 2003). These in turn, either singly or synergistically, could influence population dynamics (Bain *et al.* In review).

But strong behavioral responses of animals to disturbance does not always indicate population-level effects. Indeed, inter-specific variability in site fidelity and availability of alternative suitable habitat make it difficult to infer population-level consequences from inter-specific variability in sensitivity to disturbance (Gill *et al.* 2001). One can not protect all wildlife species from all anthropogenic impacts. Instead, Gill and colleagues advocate that we “concentrate research and protection efforts on species that are threatened or whose populations are declining, and for which human disturbance is implicated as a possible cause.”

Kruse (1990) and Williams *et al.* (2002ab) demonstrated short-term behavioral changes in Northern Resident killer whales associated with vessel traffic. However, for southern resident killer whales, even subtle behavioral responses to boats have not been reported in the primary literature.

Whalewatching is a vital part of the economies of many coastal communities in the northeast Pacific. Hoyt (2001) assessed the value of the overall whale-watching industry in Washington at \$13.6 million and in British Columbia at \$69.1 million. In addition, sportfishing and opportunistic whalewatching have become important parts of the lives of the people of this area. Thus there should at least be enough evidence to justify a precautionary management strategy to justify the economic hardship that regulating these activities would cause. Further, conservation strategies that only regulate boat traffic around whales are token gestures if boat traffic is playing a negligible role in the whale population's current depleted status. They would give the public a false sense that something is being done to protect the population, while other, more beneficial tasks, such as improving salmon returns, might go untended.

It is important then to measure the effects of boat traffic on southern resident killer whales, and to put any potential effects in the context of other known threats.

## Methods

### Study areas

From 28 July to 27 September 2003, a land-based team of observers monitored behavior of whales and activity of boats from two study sites (Figure 1). One site (hereafter referred to as the North Site) was located at  $48^{\circ} 30.561' \text{ N}$ ,  $123^{\circ} 8.494' \text{ W}$  at an altitude of approximately 99m above mean lower low water. This site was chosen because its height offered an expansive and unobstructed view, whales were known to pass it frequently while traveling close to shore, and it was located adjacent to the voluntary no-boat zone at Lime Kiln State Park.

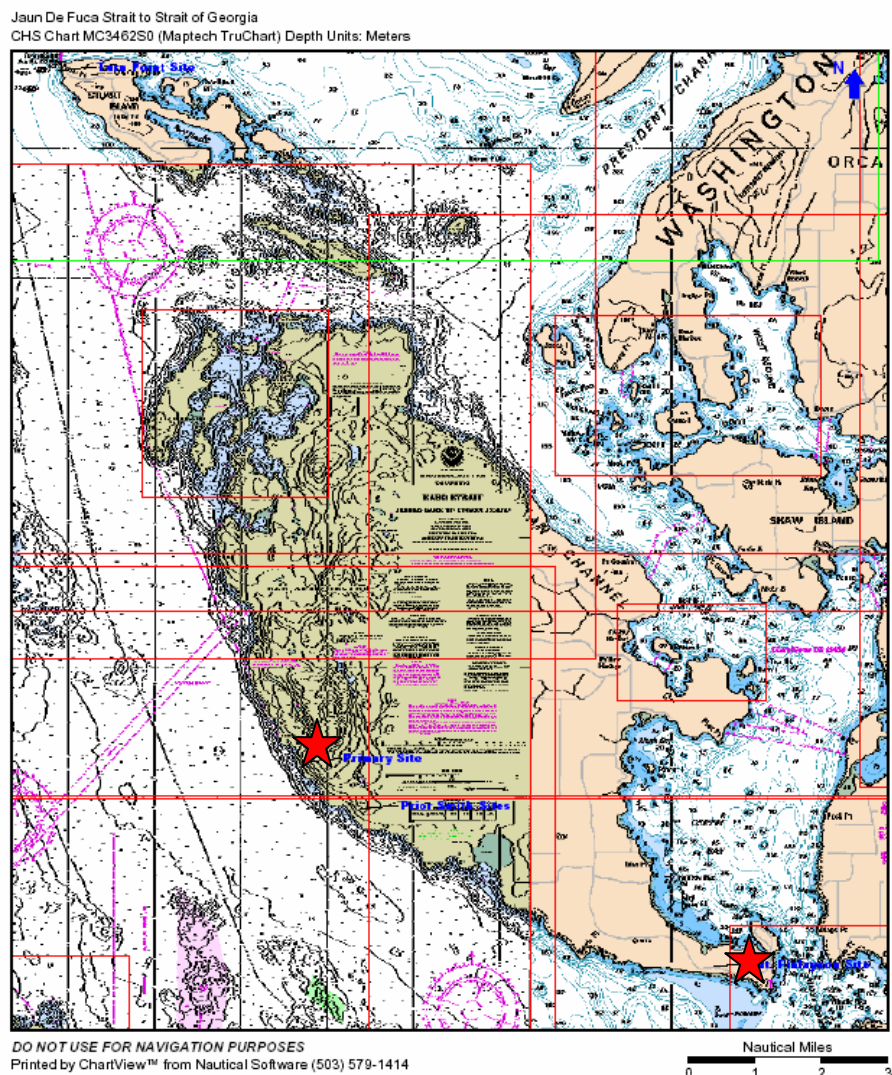


Figure 1. The study area, with the North and South sites marked with red stars.

The other (South) site was located at Mt. Finlayson, near the southeast corner of San Juan Island. This site had sufficient height (72m) and the view was

unobstructed. Further, whales have been reported to use this area heavily for foraging, whereas the North site appeared to be used primarily for travel and socializing (Felleman et al. 1991, Hoelzel 1993). Together, these sites were chosen to maximize sample size and to allow the behavioral observations to include the entire repertoire of the population.

The team worked for 62 days in summer 2003. In total, 412 hours were spent searching for whales, or monitoring their behavior. Of these 62 days of research effort, whales were present on 38 days and absent on 24 days.

### *Research Teams*

The study design involved two simultaneous data collection protocols. One observer collected broad-scale samples of the activities of all whales in the study area at 15-minute intervals. The rest of the team collected fine-scale, continuous observations of a focal animal. The two methods will be referred to subsequently as scan-sampling and theodolite tracking respectively, and are described in greater detail below. The team worked from 6 a.m. until 10 a.m., seven days per week, and then worked on an on-call basis daily until approximately 6 p.m. The exact timing of the research schedule was modified on an *ad hoc* basis from one day to the next, based on a combination of reports from monitoring of VHF commercial traffic and the local sighting network and weather conditions, in order to maximize time spent observing whales in the absence of boats.

### *Scan-sampling of focal groups*

Scan samples of group (or individual) activity were recorded every 15 minutes. A focal group was defined as animals within 10 body lengths of one another at the time of a scan-sample observation. Thus, our subsequent use of this term implies nothing about the relatedness of animals within a group. Similarly, focal groups could be of size one. When possible, activity was recorded for each identifiable individual. When individuals were too far away to be identified, their identity was assigned to categories based on size (e.g., calf, juvenile, adult female, subadult male, adult male).

The activity of the focal group was recorded every 15min using the following definitions:

Rest: characterized by prolonged surfacing in contrast to the rolling motion typically observed during travel

1. Deep rest, hanging, logging: whales do not progress through the water
2. Resting travel, slow travel: whales progress through the water, although they may not make forward progress over the ground.

Travel: characterized by a rolling motion at the surface, progress through the water, and membership in a subgroup of more than four individuals

3. Moderate travel, medium travel: travel in which whales do not porpoise
4. Fast travel: travel which includes porpoising

Forage: characterized by progress through the water by lone individuals or while a member of a subgroup of four or fewer individuals

5. Dispersed travel: foraging in a directional manner
6. Milling, feeding, pursuit of prey: foraging involving changes in direction

Socialize: interaction with other whales, or other species in a non predator-prey context

7. Tactile interactions: socializing that involves touching another whale, such as petting or nudging
8. Display: socializing that does not involve touching, but may include behaviors such as spy hops, tail slaps and breaches

Object play: tactile interaction with an object such as kelp, wood or fish (in a manner not related to feeding)

9. Kelping, object play: (note, when kelping also involves tactile interaction, count it as tactile interaction rather than object play.)

These sub-categories could be combined to either match the categories described by Ford *et al.* (2001) or Smith (unpublished data). A focal follow was treated as one sample of sequential behavioral state samples. We were interested in first-order transition in behavior, *i.e.* the likelihood that when a group was in State A that they would be in State B 15 minutes later (*i.e.*, at the next scan). This sequence of discrete time samples could be treated as a Markov chain (Lusseau 2003, 2004) because it was ergodic: a group could transit from any state to another (there was no constraint preventing whales to switch between some states and others) and the sequence was bounded by time and therefore no negative values could be expected. In addition to transitions to other behavior states, the group could cease to exist due to changes in group membership (through fission or fusion with other individuals) or could leave the study area.

At the time of each scan, the number of whale-oriented and non-whale-oriented vessels were recorded for distances within 100 m, 400m and 1000m of the animal(s). Distances were estimated visually as range rings around focal animals or groups, but checked with a theodolite when possible. These were used as candidate explanatory covariates, to assess whether the probability of animals switching among activity states varied as a function of boat traffic.

We therefore constructed a transition matrix, representing the probabilities for whales to be observed in a State *i* at time  $t = x$  (in minutes) and subsequently in State *j* at the next sampling event ( $t = x + 15$ ):

$p_{ij} = \frac{e_{ij}}{\sum_k e_{ik}}$  where  $e_{ij}$  is the total number of times the transition was observed and

$\sum_k e_{ik}$  is the total number of time State  $i$  was observed as the starting state.

The Perron-Frobenius theorem could be applied because of the ergodic nature of this transition matrix; its long-term behavior, *i.e.*, the amount of time that the whales spent in each behavioral state could be approximated by the left eigenvector of the dominant eigenvalue of the matrix (Lusseau 2003).

Behavioral transition during which boats were present within 100m of the whale were also separated from the ones during which boats were absent, in order to detect whether the presence of boats affected the likelihood to go from one state to another (Lusseau 2003). We first tallied both types of transitions in two separate matrices. We then used a log-linear analysis, using SPSS (SPSS, Inc.), to compare these two matrices and tested whether the effect “boat presence X preceding behavior X succeeding behavior”, *i.e.*, the effect representing boat presence affecting the transition in behavioral state, could significantly explain the variance observed in the two matrices. The log-linear analysis is reminiscent of a general linear analysis but applied to count data. In our case we have three independent variables: boat presence, preceding behavior, and succeeding behavior. To assess the three-way effect, we compared the all two-way models (preceding behavior X succeeding behavior, preceding behavior X boat presence, succeeding behavior X boat presence) to the fully saturated model because the only difference between these two models is the effect we are trying to assess (the three-way interaction). The comparison was achieved by subtracting the maximum likelihood (approximated using  $G^2$ ) of the all two-way model from the one of the fully saturated model and testing the significance of this difference.

We also compared the transition probability matrices to quantitatively assess whether some transitions were more, or less, likely to occur when boats were present. We subtracted the each transition probability from the boat present matrix from the control (*i.e.*, no-boat) matrix. This process was repeated using 400m and 1000m as the criterion for establishing boat presence near the whale.

Ultimately, this approach can be used to calculate stable, unbiased time-activity budgets, which can be converted to rough estimates of energy expenditure (Kriete 1995).

This same process was repeated for the spacing behavior of the group (*i.e.*, whether focal groups were swimming together tightly, loosely or dispersed), which was also recorded every 15 minutes.

These data also allowed estimation of the proportion of individuals within 100, 400, or 1000m of the nearest vessel.

#### *Theodolite tracking of focal individuals*

The theodolite tracking team consisted of three individuals that moved between the two study sites. The team recorded boat and whale positions and activity using a

Pentax ETH-10D theodolite interfaced to a PC-compatible computer running Theoprog (Williams et al. 2002ab), a Bushnell 40x spotting scope, binoculars, and a mini-DV camera.

As whales entered the field of view from a study site, a focal individual was selected. This individual was identified based on Ford et al. (2000) and more recent catalogs (van Ginneken *et al.* 2000) and tracked for at least 20 minutes. After a tracking session was completed, a new focal individual was selected, if possible. Individuals were drawn as evenly as practicable from all pods, age, and sex classes. The theodolite was used to record position of the focal individual at as many surfacings as possible, and the spotting scope and computer operators, who had a wider field of view, watched for surfacings missed by the theodolite operator, to ensure an accurate record of surface behavior. While the focal whale appeared to be down on a long dive, the theodolite operator recorded vessel positions. In addition to recording positions of boats and whales, Theoprog was used to record activity states, behavioral events (e.g., respirations and surface active behaviors such as breaches) and other notes (Williams *et al.* 2002ab).

Summaries of behavioral data were calculated for each track. These data were subjected to exploratory analyses, treating vessel variables as independent variables and whale variables as dependent variables.

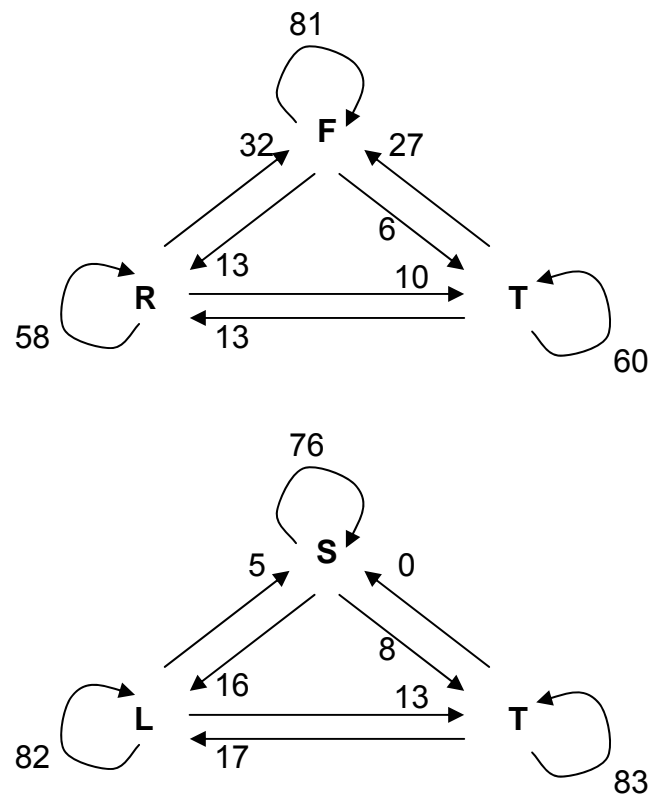
## Results

### *Scan-sampling of focal groups*

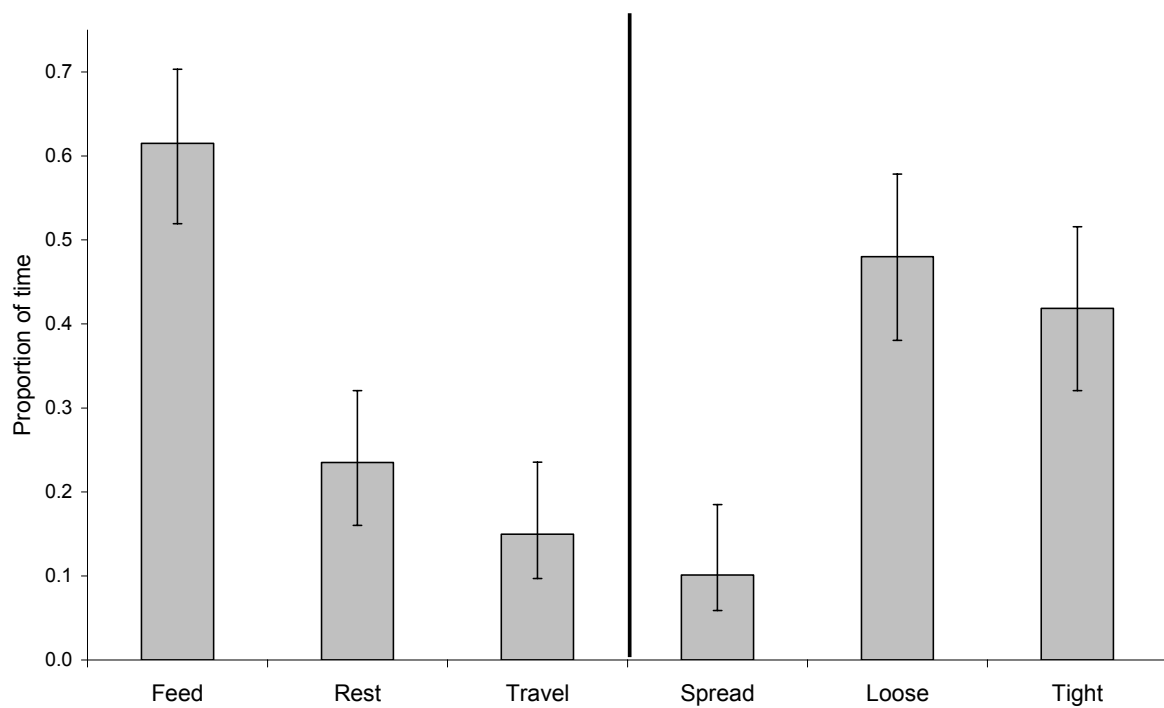
From 28 July to 27 September 2003, there were 79 behavioral transition samples collected, representing cumulatively 107 1<sup>st</sup>-degree transitions. Each sample lasted on average 1.3 transitions (SD = 0.62; max = 3). Socializing was only observed three times, involved in 3 transitions, and therefore this state was not considered in any analyses. Because of some missing data there were fewer transitions recorded on group spacing (94 transitions). This sample size did not allow testing for the effect of boat presence on spacing behavior.

When in any given activity state, focal groups were most likely to stay in the same state (Figure 2). When the animals ended a resting or traveling bout they were most likely to initiate a feeding bout afterwards. These variations in behavioral transition probabilities show that killer whales spent most of their time feeding in the areas studied (Figure 3).

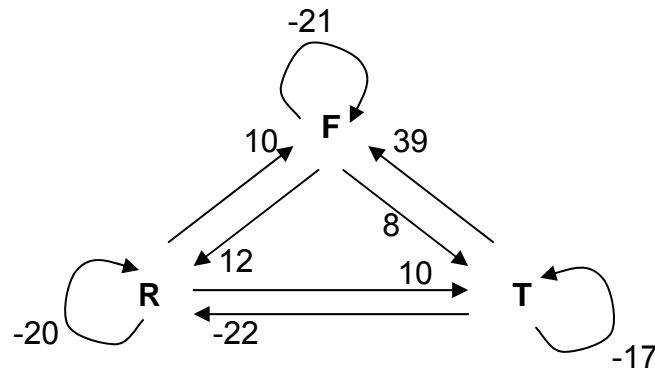
The effect of boat presence in the vicinity of the focal whales was difficult to assess due to small sample size. Using a log-linear analysis we could not detect any effect of boat presence within 100m of the whales, even though some non-significant trends could be detected. The log-linear analysis assessed whether the presence of boats affected the likelihood that a whale would switch from a state to another. This effect was tested by comparing the fully saturated model to a model considering all 2-way interactions ( $G^2 = 6.82$ ,  $df = 4$ ,  $p = 0.15$ ). It appeared by the likelihood to stay feeding when a group was feeding was decreased by boat presence.



**Figure 2.** Probability (in %) for a focal group of killer whales to switch from one activity state to another. A, behavioral state; F stands for Feeding, R for Resting and T for Travelling. B, spacing state; S stands for Spread, L for Loose and T for Tight.



**Figure 3.** Proportion of time spent in each behavioral (left panel) and spacing (right panel) state during the study period. Error bars are 95% confidence intervals around the proportions.

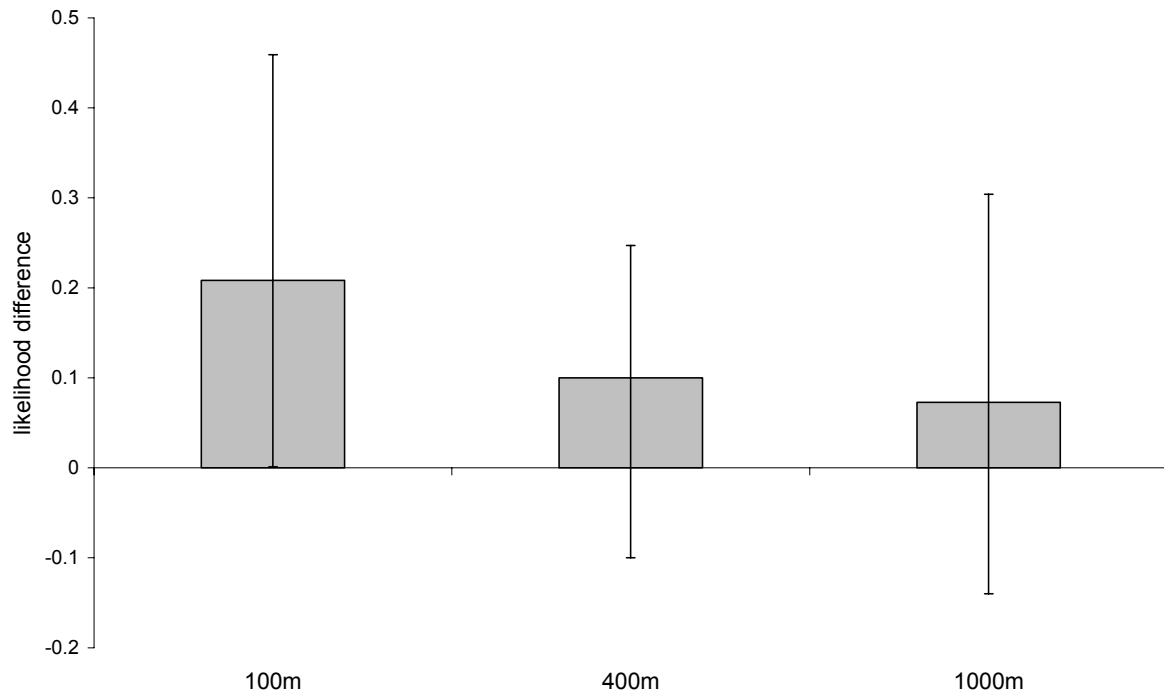


**Figure 4.** Difference in the probability to switch from one state to another depending on boat presence. Values are difference of percentages ( $p_{\text{boat}} - p_{\text{control}}$ ) and a negative value represents a decrease in the probability to switch from one state to another with boats present. Because of the small sample size, and the non-significant result of the log-linear analysis, these values are purely indicative.

Previous studies with northern resident killer whales demonstrated that feeding was affected by boat presence. Since whales in our study areas spent most of their time feeding, we could test whether the likelihood that a whale group stayed feeding when it was already feeding ( $p_{F \rightarrow F}$ ) was affected by a boat being present during the transition. This transition probability was significantly reduced by boat presence (control: 0.90 vs. impact: 0.69; difference: 0.21, confidence interval of the difference: 0.001-0.459; Figure 4).

There were not enough samples to perform log-linear analyses on the effect of boats present within 400m and 1km of the whales. However the effect of these factors could be tested on the probability to stay feeding when feeding. Boat presence at these distances did not have a significant effect on this transition probability, but a similar trend as described for boat presence within 100m was observed (Figure 5.)





**Figure 5.** Difference in the likelihood to stay feeding when feeding ( $p_{F \rightarrow F}$ ) between control and impact situations ( $p_{\text{control}} - p_{\text{impact}}$ ) depending whether some boats were present within 100m, 400m, or 1000m of the focal whales. Error bars are 95% confidence intervals for the difference. If the interval includes 0, the difference is not significant at the conventional ( $p < 0.05$ ) level.

#### *Theodolite tracking of focal individuals*

We collected 31 tracks that were at least 20min in duration. An additional 14 tracks between 15 and 20min in length were recorded. Previous work (Kriete 1995) indicated that tracks that were very much shorter than 1000s (approximately 16min) had the potential to be biased for some response variables.

Given the small sample size generally, and the paucity of no-boat tracks specifically, a discussion between NMFS and the contractors was held on how best to proceed. It was agreed that the late start to this study contributed to the small number of control observations, and that the study would benefit from a larger sample size. To that end, the contractors agreed to reallocate the budget for data analysis and report writing into a May, 2004 field season, when no-boat tracks were more feasible to collect. For illustrative purposes, one exploratory correlation between whale swim speed and the maximum number of vessels ever observed within 100m of the focal animal during a track is shown in Figure 6. However, no rigorous statistical analyses were conducted on the 2003 tracks, and are pending analysis in the 2004 contract.

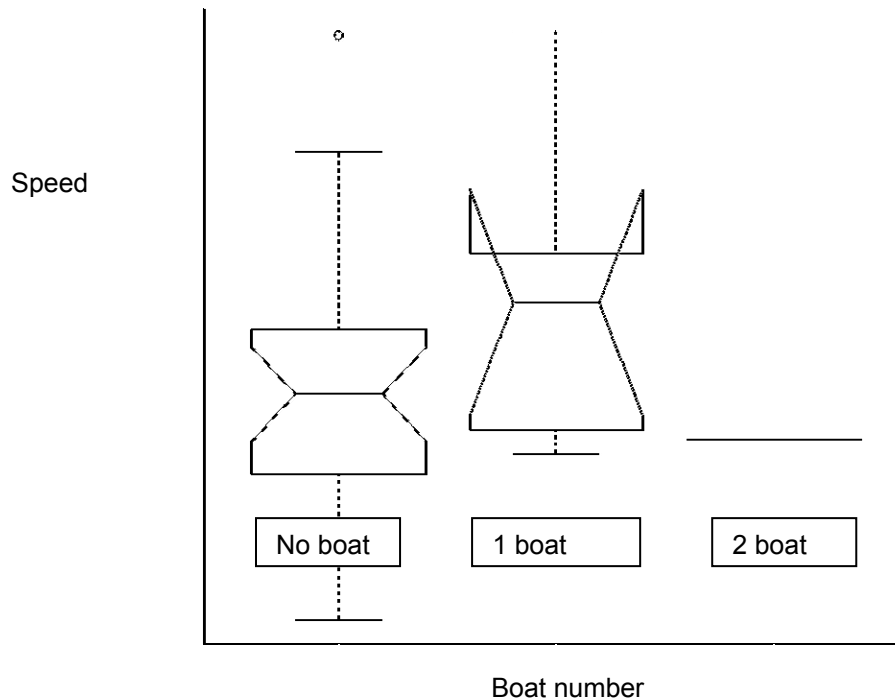


Figure 6. Box-plots showing median (notch) swim speeds of whales with no, one and two boats within 100m. While no attempt was made to assess statistical significance of this difference with such a small sample size, the figure illustrates how such data may be analyzed with more information available.

## Discussion

Sample size was a major problem that affected the reliability with which boat impact could be assessed. If the study had been started at the beginning of the summer, perhaps enough samples could have been collected to assess some of the effects. Even then, a multi-year study will be necessary to collect enough samples for the effect sizes measured here to be found significant at the conventional level.

However, the direction of trends observed in the Markov-chain analyses are in the same direction as those observed in a recent study of the northern resident killer whale community (Williams, 2004; Williams, Lusseau and Hammond, in prep.). Feeding seemed to be reduced with boat presence. Intriguingly, the magnitude of this effect appeared to decrease with the distance between boats and whales. However, the veracity or extent of these effects could not be demonstrated from the few samples collected in this study.

The relationship between effect size and distance is interesting because it correlates with what one would expect if boat noise were the principal source of disturbance. Previous studies have shown that the active acoustic foraging zone of killer whales can be reduced or masked by boat noise (Erbe 2002; Bain and Dahlheim 1994, and see Bain *et al.* In review) and therefore the closer boats are the more this zone is reduced (Williams *et al.* 2002b), leading to foraging disruption as observed here. Of course, this effect would be confounded by the engine type, and the speed at which boats were operating, which were not considered in these simple presence/absence analyses.

The main findings of this study warrant an extension of the data collection to assess whether these preliminary results can be replicated with a larger sample size. In addition, if these preliminary findings were supported with a larger sample size, then the analytical framework outlined in this study would allow us to determine the point at which boats could approach whales in order not to disrupt their foraging activity.

## Bibliography

- Bain, D. E. 1986. Acoustic behavior of *Orcinus*: sequences, periodicity, behavioral correlates and an automated technique for call classification. In (B. C. Kirkevold and J. S. Lockard, eds.) Behavioral Biology of Killer Whales. Alan R. Liss. New York. 335-371.
- Bain, D. E. and M. E. Dahlheim. 1994. Effects of masking noise on detection thresholds of killer whales. Pages 243-256 in T. R. Loughlin, editor. Marine mammals and the *Exxon Valdez*. Academic Press, San Diego, California.
- Bain, D. E. 2002. A model linking energetic effects of whale watching to killer whale (*Orcinus orca*) population dynamics. Friday Harbor Laboratories, University of Washington, Friday Harbor, Washington.
- Bain, D. E., Trites, A. W. and Williams, R. In Review. A model linking energetic effects of whale watching to killer whale (*Orcinus orca*) population dynamics. *Journal of Cetacean Research and Management*.
- DeNardo, C., Dougherty, M., Hastie, G.D., Leaper, R., Wilson, B., and Thompson, P.M. 2001. A new technique for investigating variability in spatial relationships within groups of free ranging cetaceans. *J. Appl. Ecol.* 38: 888-895.
- Erbe, C. 2002. Underwater noise of whale-watching boats and potential effects on killer whales (*Orcinus orca*), based on an acoustic impact model. *Marine Mammal Science* 18:394-418.
- Felleman, F. L., J. R. Heimlich-Boran and R. W. Osborne. 1991. Feeding Ecology of the killer whale (*Orcinus orca*). In (K. W. Pryor and K. S. Norris, eds.) Dolphin Societies: Discoveries and Puzzles. University of California Press. Berkeley. 113-147.
- Foote, A.D., R.W. Osborne, and A.R. Hoesel. 2004. Whale-call response to masking boat noise. *Nature* 428(April 29): 910.
- Ford, J. K. B., G. M. Ellis and K. C. Balcomb. 2000. Killer whales, second edition. University of Washington Press. Seattle. 104 pp.

- Galicia, E. and G. A. Baldassare. 1997. Effects of motorized tourboats on the behavior of nonbreeding American flamingos in Yucatan, Mexico. *Conservation Biology* **11**(5):1159-1165.
- Gill, J. A., Norris, K. and Sutherland, W. J. 2001. Why behavioural responses may not reflect the population consequences of human disturbance. *Biological Conservation* **97**: 265-268.
- Hoelzel, A.R. 1993. Foraging behaviour and social group dynamics in Puget-Sound killer whales. *Anim. Behav.* **45**(3):581-91.
- Hoyt, E. 2001. Whale watching 2001: Worldwide tourism numbers, expenditures and expanding socioeconomic benefits. International Fund For Animal Welfare, Yarmouth, Massachusetts.
- Kriete, B. 1995. Bionergetics in the killer whale, *Orcinus orca*. Ph.D. Thesis. University of British Columbia. 138 pp.
- Kruse, S. 1991. The interactions between killer whales and boats in Johnstone Strait, B.C. Pages 149-159. In: K. Pryor and K. Norris (eds.) *Dolphin Societies*, University of California Press. Berkeley.
- Lacy, K.E., and E.P. Martins. 2003. The effect of anthropogenic habitat usage on the social behavior of a vulnerable species, *Cyclura nubila*. *Animal Conservation* **6**: 3-9.
- Lusseau, D. 2003. The effects of tour boats on the behavior of bottlenose dolphins: Using Markov chains to model anthropogenic impacts. *Conservation Biology*. **17**: 1785-1793.
- Ray, R. D., M. L. Carlson, M. A. Carlson, T. M. Carlson and J. D. Upson. 1986. Behavioral and respiratory synchronization quantified in a pair of captive killer whales. In (B. C. Kirkevold and J. S. Lockard, eds.) *Behavioral Biology of Killer Whales*. Alan R. Liss. New York. 187-209.
- Safina, C., and J. Burger. 1983. Effects of human disturbance on reproductive success in the black skimmer. *Condor* **85**:164-171.
- Smith, J. C. and D. E. Bain. 2002. Theodolite study of the effects of vessel traffic on killer whales (*Orcinus orca*) in the near-shore waters of Washington State: 2001 field season summary. Unpublished report.
- SPSS, Inc. 2003. Systat. [www.systat.com](http://www.systat.com).
- Van Ginneken, A., D. Ellifrit, and K. C. Balcomb, III. 2000. Official orca survey field guide. Center for Whale Research, Friday Harbor, Washington.
- Venables, W.N. and Ripley, B.D. 2002. *Modern Applied Statistics with S*. New York: Springer.
- Wiles, G.J. 2004. Washington State status report for the killer whale. Washington

Department Fish and Wildlife, Olympia. 106 pp.

Williams, R. M. 1999. Behavioural responses of killer whales to whale-watching: opportunistic observations and experimental approaches. Master's Thesis. University of British Columbia. 61 pp.

Williams, R., Trites, A.W. and Bain, D.E. 2002a. Behavioural responses of killer whales to whale-watching traffic: opportunistic observations and experimental approaches. *J. Zool., London*. **256**: 255-70.

Williams, R., D. E. Bain, J. K. B. Ford and A. W. Trites. 2002b. Behavioural responses of male killer whales to a 'leapfrogging' vessel. *J. Cetacean Res. Manage.* **4**: 305–310.